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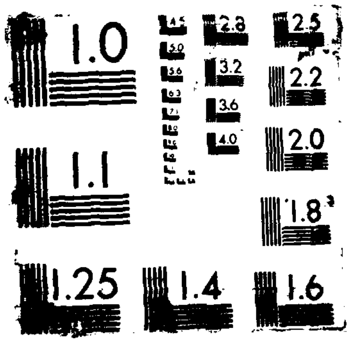
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An Elastomer Test Machine (ETM) has been designed, constructed and tested with samples provided by the Army Materials Technology Laboratories, Watertown, Mas. The results indicate that the ETM is able to produce accelerated aging of elastomer compounds and provides reliable data to assess their resistance to damage in the (i) stationary, (ii) tilted and (iii) rotational modes. In the linear mode of operation there is a lack of synchronization of the linearly oscillating table with the press action. As a result, the data obtained in the linear mode are consistent. ETM is provided with a load cell and a temperature controller with their associated digital indicators.

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ELASTOMER TEST MACHINE

U.S. ARMY - ERO CONTRACT NO.

DAJA 45-85-c-0044

FINAL REPORT: MAY 1988

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INTRODUCTION

An Elastomer Test machine has been designed and constructed as a unique test bed for elastomer compounds which are used on road vehicles and caterpillar tracks. The machine simulates complex wearing actions upon the elastomers. The final report describes the machine, states its specifications and given an account of interfacing of this machine to a macrocomputer and its use in testing various elastomer compounds, thus effectively testing the machine itself (Keywords: Presses (machinery), JES

ELASTOMER TEST MACHINE (ETM)

Figure 1 shows a photograph of the machine. It may best be described in sections thus:

(i) The Pneumatic Ram

This is a compressed air driven, six ton half body press, manufactured by Rother Machine Tools Limited. It is designed to operate from an air supply of 80 p.s.i.g. It may be operated in a 'single shot' mode, impacting upon the sample when the guard is lowered, and lifting from the samples when the guard is raised, or in 'auto' mode in which the ram repeatedly impacts and lifts from the sample automatically via a system of valves. The frequency of the ram may be adjusted in the range from 1 to 4 per second by varying the stroke length of the piston, and the exhaust setting of the autocycle valves. The ram head incorporates a 'DONUT' type load Cell which measures the load experienced by the sample for each impact, and an inter-changeable tool bit so that different abrasive surfaces may be simulated. The present tool is a standard machine tool, modified to increase abrasive forces along its lower edge without producing immediate cutting of the sample. Figure 2 provides a photograph of the cutting tool in actual size.

(ii) The Sample Holder, Turntable and Linear Platform

The sample holder is designed to contain 2.5 inch square samples which fit tightly in the top of the holder to produce a good thermal contact (figure 3). The top of the holder is formed from a copper block and houses two 100 watt cartridge heaters and a J-type thermocouple. The base of the holder is isolated from the heated section by four steel pins. The sample holder sits on the platform of the turntable which may be tilted up to 30 degrees by releasing a securing lever. This achieves simulation of shearing forces on the sample other than those perpendicular to the surface.

When the platform is set horizontally, 'ROTATIONAL' mode may be used. The turntable is driven via a toothed belt, by a 1HP electric motor. It is capable of up to 144 rpm in either a clockwise or anticlockwise direction. Impacts upon the sample in this mode produce the angular, twisting forces experienced when an OTR vehicle turns.

The turntable is mounted on a platform which may be driven in a linear manner by two parallel air cylinders, the air supply being fed by the same source as the ram. The frequency of the platform's linear oscillations is controlled by the exhaust valves at each end of the cylinder and is in the range of 35-83 cpm. The platform has shock absorbers at the ends of its travel in order to prevent damage to the machine at high speeds. The linear mode simulates lateral cutting forces parallel to the surface of the sample.

(iii) The Control Panel

All functions of the machine may be controlled from this panel which is located at the front of the machine, below the linear platform. Its position facilitates operation from a seated position. The panel houses switches, control valves and pressure gauges for the air supply for the ram and the linear platform. Control valves to regulate the exhaust setting for the ram and the linear platform are also located on this panel, together with the switches (a) to change between linear and rotational modes, (b) for the motor speed control and (c) for the directional control of the turntable.

The air supply to the ETM is controlled from the panel by a master switch. The control panel also contains a Eurotherm (model 820) single loop communicating controller which controls the temperature of the sample via a feedback loop. A digital temperature indicator on the panel provides a measure of the sample temperature.

(iv) The Load Cell and Display

The D-type load cell was supplied by RDP Electronics Limited and is calibrated up to 5,000 lbs. It measures directly the load experienced by the sample at the point of impact. The calibration unit and display has an output of +10V for a full scale deflection of 20,000 lbs and produces an output of approximately 0.1V for a typical impact of about 200lbs.

(v) The Microsystem

The present contract provides no funding for the automated data recording and operation of the machine. However, for the purpose of testing the machine the School of Electronic Engineering Sciences kindly provided a loan of a CIL Microsystem PCI 6380 interface and a Ferranti PC860-XT computer. The Microsystem PCI 6380 interface system is a Z80 based multi-function instrument which has 8 differential input channels, 4 output channels and 4 relays on the front panel, with a 15 bit resolution digital output at the rear. It is fitted with 4K bytes of EPROM, carrying a software support package and 6K bytes of RAM, 4K of which is available to the user for the data and programming. The PCI 6380 is designed to operate with either the IEEE-488 (GPIB) bus controller or with RS232 computers. The IEEE-488 (GPIB) interface card has been used for the present operation and it provides a means by which an IBM 'clone' PC may communicate with up to 15 compatible devices. The Ferranti PC860-XT is an IBM 'clone' machine with a 10 Mbyte Winchester disc (uprated), a 5.25 inch floppy disc drive and a relatively slow internal clock speed of 4.7 MHz. The language used to control the interface from the computer is a form of BASIC common to most IBM 'clones' called G.W. BASIC. BASIC, however, is a relatively slow and unstructured language and further work should use a faster, more flexible language, such as PASCAL.

TESTING: PROBLEMS ENCOUNTERED

During the testing it was noticed that the frequency of the ram slowed after about 40 impacts in any run. The was due to the air supply from the compressor being unable to keep the pressure at 80 p.s.i.g. when the ram is running automatically. At the same time it was noticed that the data collected at lower frequencies were of better quality.

A problem encountered for the linear mode was due to the common air supply between the ram and the linear platform. If an impact was too deep and/or the exhaust setting of the table was too low, the table was found to stall, as insufficient air pressure was available to the cylinders driving the table. The values of exhaust setting, and the depth of penetration for which stalling occurs, is independent of the mechanical strength of the sample. This problem should be reduced when the linear platform has its own air supply.

As the sample holder is mounted on a turntable, the electrical connections to it must pass through a slip-ring and brush arrangement. At present the brushes are standard 'alternator' type carbon brushes on a steel ring. Unfortunately, this arrangement introduces an inconsistent resistive component into the link, which is a problem for transmission of the thermocouple voltage of very small magnitude. This effectively introduces a break in the feedback system of the Eurotherm 820. In most cases the break in the feedback link is only partial, and the temperature controller 'sees' only a fraction of the voltage transmitted by the thermocouple, causing an overheating of the sample.

RESULTS AND DISCUSSION

The following samples which have been provided by the Army Materials Technology Laboratories, were tested with the ETM at U.C.N.W.

RUBBER

15 TP14AX
15 NAT25A
15 SBR26
NBR 6

FIBREGLASS REINFORCED RUBBER

0001 AM
0001 AN
0001 AE

POLYURETHANE

ECP 1
ECP 2

Morbay 2690
Budd 20
1080 (Polyester)) Gallagher Corporation
A8 (Polyester))

All samples displayed a significant amount of damage during the test. The rubber based samples tended to show marked differences in the type of wear experienced, compared with urethane based samples. The rubber based samples, in general, seemed to suffer more from the abrasive action of the tool passing over their surfaces in both rotational and linear modes than cutting of the sample which occurs at greater depths of penetration. This may be due to the fact that the rubber-based samples are generally softer and have greater 'stiction' properties than the polyurethane samples. On the other hand, the polyurethane samples were found to slide easily beneath the flat part of the tool with very little abrasion. However, they were prone to cutting along the path traced by the deepest point of penetration, i.e., the edge of the tool bit. Once this cutting occurs, damage often spreads rapidly from the area of the cut to produce final damage patterns similar to those for the rubber based samples.

Experimental tests consisted of a measurement of each impact load on the material surface delivered by the ram head via the tool. These data were recorded for various modes of operation and graphs were plotted for load/time in autocycle mode. Figure 4 shows a typical behaviour of such a load/time plot. The peak load response occurs when the ram tool head hits the surface of the specimen under test. It may be observed that this impact load dissipates during the period the tool head is in contact with the sample. The load reading then drops to zero as the ram tool head lifts away from the sample surface. This pattern is then repeated at each successive impact. The magnitude and form of these features vary for different samples and it is this variation which may be used for characterisation and ageing of samples. This form of comparison relies on impacts being consistently made on the same point or area of the sample, so that wear over that area is uniform and the pattern of the load time graph will change as the wear on the sample increases. For rotational stationary and tilted modes such plots provided good repeatability. However, for the linear mode, impacts occurred at different frequencies over different parts of the sample as there is no synchronisation between the ram and the linear platform at present. It would be necessary to provide such a synchronisation for obtaining useful information of sample ageing in the linear mode. No results of the tests in the linear mode are provided in this report.

In general, there are two 'measures' for the sample quality which may be determined from the load/time plots. The first is the percentage difference between the initial and the final average impact values. The second is the rate at which the load values 'tail off' after each impact. The slower the tail off, the better is the quality of the sample, as it has resisted loss of material, and is still resisting the impact. Rapid 'tail off' indicates that the sample is offering little resistance to the impact, and in general, is accompanied by loss of material. The cutting of the sample is indicated on the load/time graph by the presence of a peak at the beginning of the impact. The larger the peak, compared to the rest of the impact, the more cutting has occurred.

SAMPLE 15 TP14AX 2½" x 2½" x 1 1/8"

It is a matt block rubber based sample designated 'reference rubber'. In the stationary mode, the sample was roughened slightly over the whole impact area. A very slight cut formed at the deepest point of penetration, and a greyish boundary formed around the edge of the impact area. Tilted cutting occurs at 9mm and 15mm penetration and the depth of cut was observed to be 4mm. In the rotational mode the sample was cut during the first rotational test, but only at the deepest point of penetration. After about 120 impacts during 16 rmp/6mm penetration test, the material begins to come free at the deepest point of impact. Abrasive forces begin to remove the material from the outer edges of the impact when the depth of cut is increased to 9mm.

SAMPLE 15 NAT 25A

15 NAT 25A is a matt black sample compared to pure rubber. At the tilted mode the sample is only cut slightly at the deepest impact setting. The sample stood up well to this test. In the rotational mode the sample was able to cope with large twisting forces without cutting. This sample showed exceptional performance in the rotational mode and suffered only 2mm cut compared to an average for the other samples of 7mm cut.

SAMPLE 15 SBR 26

This is a rubber based matt black sample with a very smooth appearance. In the stationary mode the sample showed less wear than either 15 TP14AX or 15 NAT 25A. In the tilted mode the sample suffered a cut depth of 4.5mm. In the rotational mode small pieces of sample were thrown off at faster speed. Overall, this sample performed well. The cut depth of 5mm in the rotational tests was the second best of the samples tested.

SAMPLE ECP2

ECP2 is a tan coloured sample, described as a polyester/glycol composite. It has a smooth finish and a greasy feel. In the stationary mode the sample behaved well. In the tilted mode the sample suffered a cut depth of 5.5 mm. In the rotational mode material is removed easily but the damage is limited to the point of deepest penetration. The samples show a great resistance to surface abrasive forces but has little resistance to cutting in the rotational mode.

SAMPLE ECP1

ECP1 is a transparent pale amber coloured sample described as polyether. In the stationary mode small cuts to a depth of 1mm developed. In the tilted mode the sample performed well, being cut to a depth of only 4mm with no loss of material. In the rotational mode this sample, as with ECP2, is easily cut and material broke from the surface in small lumpy pieces at 16 rpm.

SAMPLE MORBAY 2690

It is a transparent amber coloured sample, slightly darker in colour than ECP1. it is a urethane based sample. In the stationary and tilted modes the sample is badly cut to a depth of 8mm. In the rotational mode a large volume of the material had been removed at the end of the test, the remaining sample offering very little resistance to further impact.

SAMPLE 1080/A8 MOPA

This is a black polyurethane sample supplied by the Gallagher Corporation. It is described as TDI/Polyester and has a smooth glass finish. In the stationary mode cuts to a depth of 2.5 mm were produced. In the tilted mode the sample suffered severe cuts and materials were removed from several parts of the impact area. The depth of the cut was observed to be 7mm. In the rotational mode the sample lost almost twice as much material as MORBAY 2690. The damaged area has a diameter of 25mm and a cut depth of 8mm. This is a very poor sample. Rotational testing literally tore the sample apart.

SAMPLE 0001 AM

This is a reinforced rubber based sample, described as `2.5%, rubber impregnated chopped strand', the reinforcement agent being fibre glass. In the stationary mode cuts of 5mm developed during testing. In the tilted mode it did not lose any material but cut depths of 5mm developed.

The sample was able to deform around the area of impact, reducing the pressure of the cutting edge. In the rotational mode the sample did not perform well. The faster and deeper cuts were made in this mode with a removal of material in a very fine powder form. The sample was cut to a depth of 7mm.

SAMPLE 0001 AN

This is virtually identical to the sample 0001 AM, the only difference being that the level of reinforcement of the chopped fibre glass is increased to 5.0%. In the stationary mode its performance is identical to 0001 AM. In the tilted mode the sample performs less well than 0001 AM, cutting to a depth of 5.5 mm. In the rotational mode again the damage is comparable to that of 0001 AM, except that the material lost consists of slightly larger and angular pieces. Consequently, the surface damage is rougher. The cut depth in this mode was 8mm. The increase in reinforcement does little to aid the resistance of the sample. The overall performance of the rubber-impregnated chopped strands sample is poor and it has rather limited resistance to twisting.

SAMPLE 0001 AE

This is a rubber based sample, reinforced by long vertically set fibreglass strands which are clearly visible on the sides of the sample. The damage to the sample in all three modes (stationary, tilted and rotational) are comparable with 0001 AM and 0001 AN samples.

SAMPLE NBR 62

This is a matt black, rubber based sample described as a 'highly saturated nitrile. As with other non-reinforced rubber samples, NBR6 performs well. The depth of cutting in the stationary mode was only 1mm. In the tilted mode the sample also performs well. The cut depth was only 3.5 mm and there was no loss of material. In the rotational mode the sample suffered some material loss. The wear pattern was wide and shallow, showing abrasive action to be a significant cause of material loss.

SAMPLE BUDD 20

This is an amber coloured polyurethane type sample. In the stationary mode the sample produced very high load values, almost four times that for the rubber sample. The cut depth in this mode was 5mm. In the tilted mode the sample developed three distinct cuts, one each for the front, rear, and cutting edges of the tool bit. Each produced cuts of about 5mm depth. In the rotational mode the sample suffered a severe damage over an area of 15mm diameter. The damage was somewhat similar to that of MORBAY 2690 sample. This was by far the hardest sample tested and it seems to be almost brittle as it breaks up so rapidly when twisted.

At the completion of sample testing clear differences in the performances of the samples have emerged, the best samples displaying much less damage than the poorer samples. The following table shows the initial and final load values for each sample in the 9mm tests, and the percentage drop in between. The larger the drop the more the sample has been degraded by the test. This only serves to confirm what may be seen from observation of the rotational tests, but produces an objective, numerical ordering of the samples.

Sample	**Initial Load**	**Final Load**	**% Drop**
15 NAT 25A	75.8	64.8	14.6
15 SBR 26	81.2	63.0	22.5
ECP 2	201.85	154.9	23.3
ECP 1	165.0	114.6	30.7
15 TP 14-AX	182.3	89.8	50.7
0001 AN	160.3	71.5	55.4
NBR 6	132.2	58.1	56.1
BUDD 20	344.7	148.7	56.8
0001 AM	152.7	57.7	62.1
0001 AE	128.9	44.6	65.4
MORBAY 2690	288.0	84.0	70.7
1080/A8 MOPA	159.0	43.6	72.7

When synchronisation of the linear table is achieved, so that all impacts have the same form, a similar system of analysis should be possible for judging the quality of the sample in linear mode.

A further test was carried out to measure the 'hardness' of a sample, by testing its resistance to impacts of various depths in stationary mode. This was thought to be useful, as a harder sample would suffer less cutting, for the same force, in the situation encountered on the track of an 'OTR' vehicle. For samples producing similar damage in the test pattern, the harder sample would probably perform better in a real situation.

All underlined values indicate cutting of the sample.

\Depth of cut (mm) Sample	2	4	6	8	10	12	14	16
BUDD 20	40	103	187	272	398	499	612	698
1080/A8 MOPA	13	66	120	195	278	325	407	520
ECP 2	46	124	169	237	292	257	388	457
0001 AN	2	29	63	109	168	252	340	392
0001 AM	2	25	57	106	157	223	307	349
ECP 1	13	50	92	139	193	262	311	340
NBR 6	2	26	42	87	147	199	255	334
0001 AE	5	47	73	124	186	240	292	333
15TP 14-AX	1	17	56	82	136	182	248	280
15 SBR 26	1	12	32	71	108	170	203	270
15 NAT 25A	11	29	59	96	138	169	212	251

The hardness of the sample should only be used to judge between samples when their wear is similar, as many of the harder samples performed poorly as they have poor elastic properties.

The mass lost by each sample is also an important criteria for analysis. Unfortunately the samples were only weighed initially to an accuracy of ±1 gram. In many cases the mass of material lost was less than this, so these results were useless. Any future work must involve more accurate weighing of the sample to at least ±1/10th of a gram.

In judging the best sample/samples of those tested, it is the overall performance of the sample rather than any single test, that must be considered. This criterion reduces those samples which may be considered to the following:

15 SBR 26
ECP 2
15 TP 14-AX

as they are the only samples to show consistently good results for all modes of testing.

These may also be separated when volume of material lost and resistance to cutting are taken into account. This consideration produces the ordering shown above, the best overall sample being 15 SBR 26.

FURTHER WORK

(i) An important item to be included in any further work must be the synchronisation of the linear table with the press action of the ram. This may be done fairly simply by the addition of pressure switches at the ends of travel of the table, which may be used to control the lowering and raising of the ram.

This would place the impact of a known site on the sample, the linear table would then travel its full width before the ram is raised, giving each impact cycle a precisely repeated action. This should produce much more consistent and useful data, comparable to that of the rotational tests.

(ii) A further addition to the linear mode would detect the horizontal resistance offered by the sample. This would involve the addition of a pressure transducer in the horizontal plane, fitted within the sample holder, which may be interfaced using another input channel on the 6380. This would give a complete picture of the resistance to both impact, and lateral movement, offered by the sample in linear mode.

(iii) It may be possible to add 'on-site' weighing apparatus, to directly measure the rate of mass loss from each sample. The difficulty in this is the sensitivity required for the weighing device. It must be accurate to at least 1/10th of a gram, yet be able to withstand impacts of the ram which sometimes exceed 600lbs force for the harder samples.

A possible way around this is to collect the material removed, and subtract its mass from the mass of the sample, this could be done using an arrangement which sucks the loose material from the sample like a vacuum cleaner.

(iv) The slip rings transmitting the thermocouple voltage to the temperature controller must be changed from the current 'alternator' type carbon brush arrangement to a more suitable, and accurate set-up, involving silver plated rings, and silver impregnated carbon brushes.

This would reduce the losses and variations in the transmitted voltage currently experienced and allow testing at elevated temperatures to be effectively carried out.

(v) Modification or re-writing of the program to allow faster data gathering, and to change the computers role from purely being a means by which data may be gathered, stored and displayed, to a more complete system, which performs mathematical analysis on the data, to produce more quantitative results, and to further automate the operation of the machine and test pattern.

This would be done by modification of the current BASIC program, but it would probably be best to change the programming language to increase speed, as it is now clearer what is required to operate the interface and analyse the data.

CONCLUSION

The project has shown through systematically testing each sample, that the machine is able to produce a significant amount of wear in a relatively short period of time. The Elastomer Test Machine has shown itself to be, with the addition of a load cell and interface, a suitable and reliable means by which the durability of elastomer compounds may be comprehensively tested.

Appendix I

SPECIFICATION OF THE PRESENT ELASTOMER TEST MACHINE

The machine is to stimulate the wear and tear of 'elastomer compound components' as found on large 'OTR vehicles' etc. and is intended for laboratory use where there is available a source of:

1. Electrical supply at 110 volts at 60 Hz.

2. Air pressure at 80 p.s.i. max. in either line form (small compressor and storage vessel) or high pressure air bottle with suitable pressure regulation.

The machine is free standing on its own plinth, with the facility to move it between different locations. The motive power for the impacting of samples is generated by an air operated "Toggle" press capable of supplying 3 tons maximum force in either single impact or continuous cycle modes (selectable). Air supply is requirred at 80 p.s.i. (max) and both the tonnage and stroke are adjustable. A separate supply of 80 p.s.i. is required to operate the linear oscillating mode.

The sample with a max. size of 4 ins square x 2½" thick is held in a machine vice on the same vertical axis as, and under, the press "ram".

The ram head has a facility for selection from different blade forms to apply differing cut characteristics to the sample.

As well as the impact on the sample, such sample is given three modes of being presented to the line of impact.

1. Rotational

   Here the complete machine vice holding the sample is mounted on a suitable radial/thrust bearing system and is rotated by tooth belt/pulley arrangement from a decoupled motor/gearbox unit. (Such decoupling ensures no impact is transmitted through motor shaft etc.) This mode would simulate a rotational shearing force on the sample at the moment of impact.

2. Linear Oscillating

   This mode, where the complete sample mounting arrangement is given linear movement by a parallel pair of air cylinders exercises a linear shearing force on the sample at ipact. Stroke length and frequency are controlled by electro/pneumatic valve system.

3. Tilt

Here, the sample face presented to the impact is given a manually settable tilt of up to 30 degrees from the horizontal plane. This mode allows impact at planes other than normal to sample face. Such a tilting facility would not be coupled in use with either rotational or linear oscillating modes.

The complete system is microprocessor controlled for operation and storage of selective modes with a control panel on 19" rack system, withdrawable from machine cabinet.

SAMPLE

Size	4" x 4" x 2½" thick max.
Movement Modes	1 Rotational 0-3 rev/sec 2 Linear - up to 2" max. 3 Tilt 30 degrees from horizontal
Temperature Range	25-140 degrees centigrade

IMPACT

Force	Up to 6000 lbs max.
Frequency (proportional to stroke length)	1-4 per sec.
Cycle	Single or Continuous
Sample Penetration Depth	15mm max.

Elastomer Test Machine

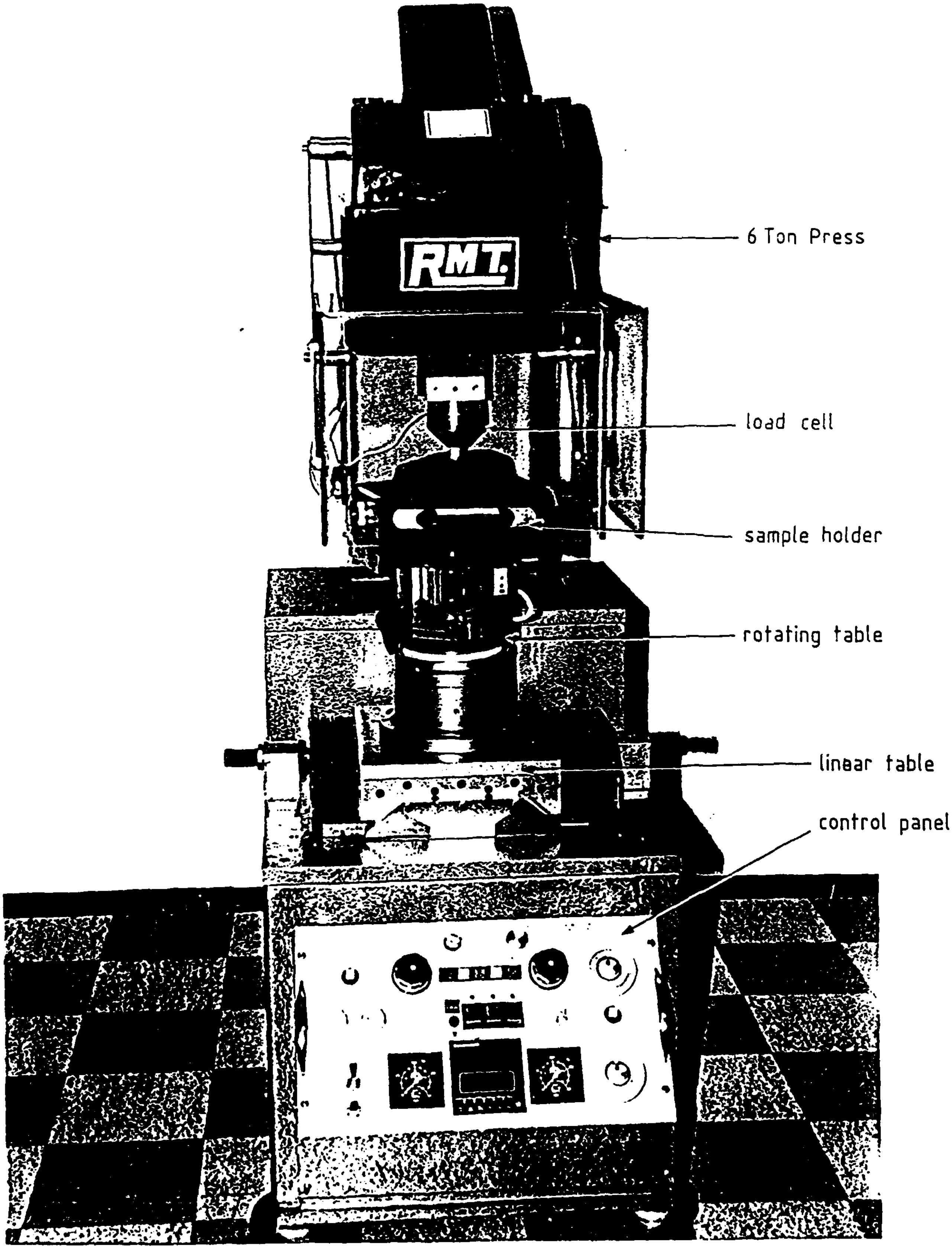
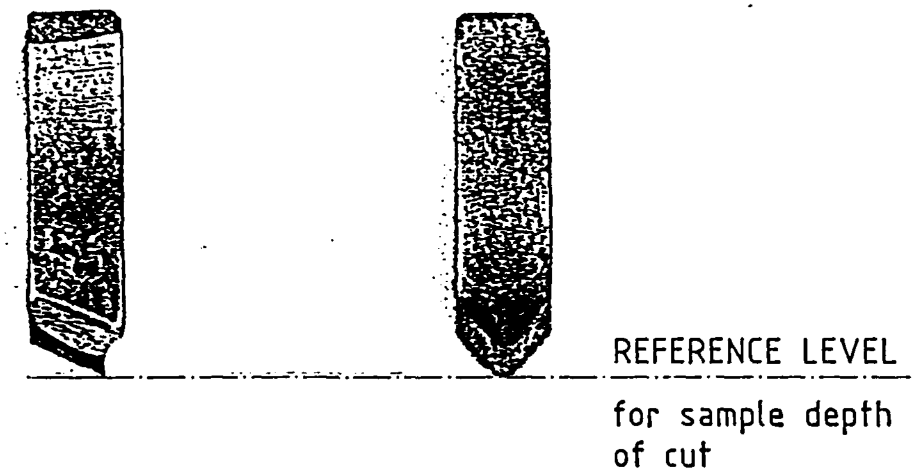


Fig. 1.



TOOL INSERT USED
ON SAMPLE TESTING
ACTUAL SIZE

Fig. 2.

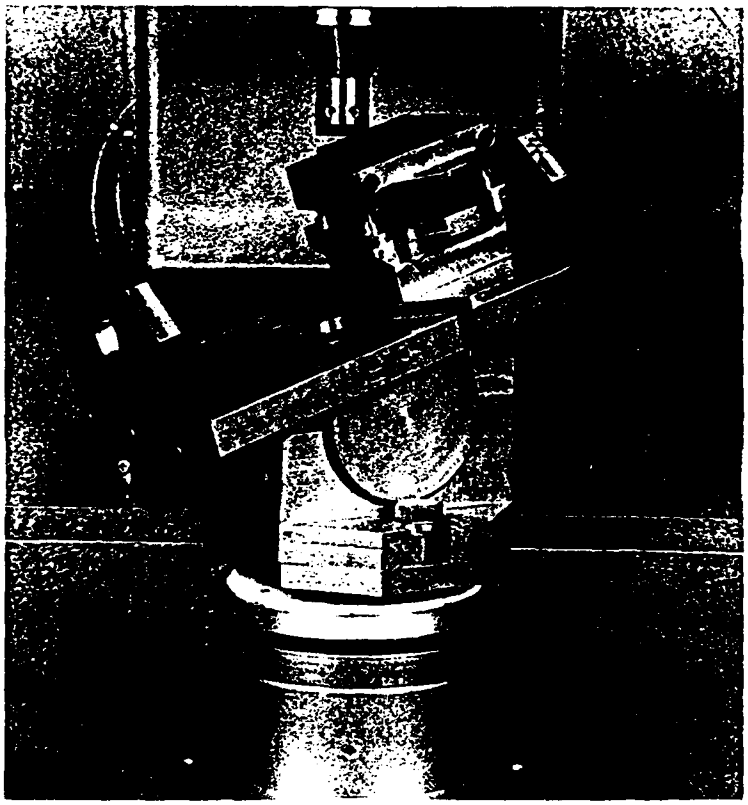
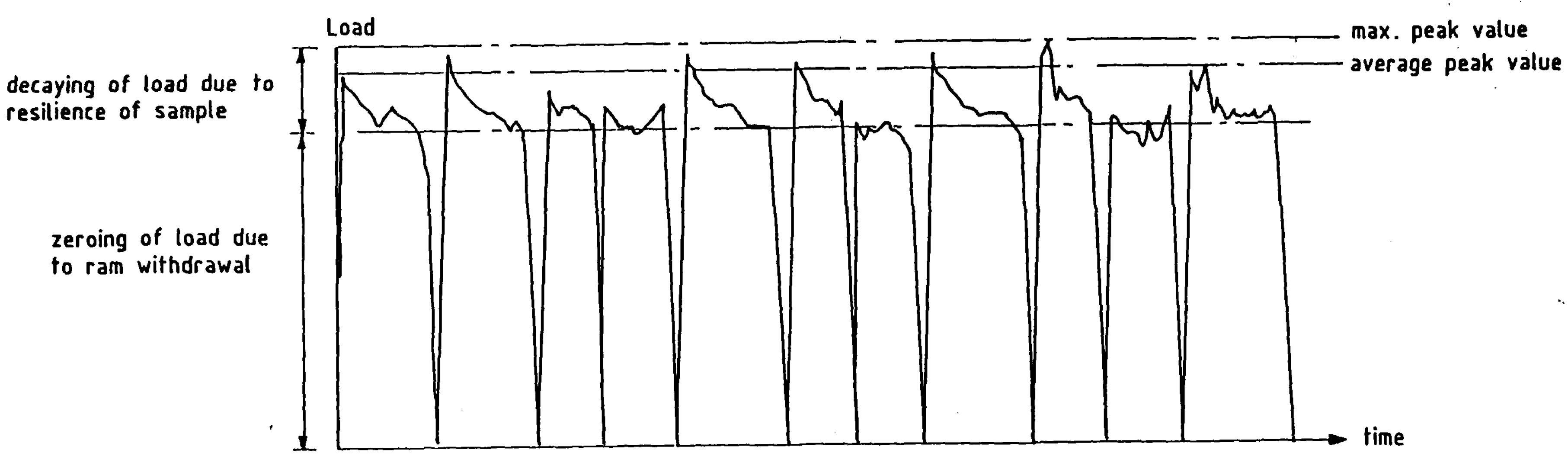


Fig. 3.

Sample Holder & Stage (Sample tilted and in stationary mode).



Typical sample load / time plot,
with machine in auto cycle mode.
Rotational mode
Fig. 4.

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